Year: 2020

Adhesion to high-performance polymers applied in dentistry: A systematic review

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Abstract: OBJECTIVE The aim of this systemic review, conducted in accordance with the PRISMA statement, was to investigate the impact of surface pretreatments on the bonding strength of high performance polymers (HPPs). METHODS Eight databases were searched through March 2019. Risk of bias was assessed and random effects meta-analyses were applied to analyze mean differences in shear bond strength (SBS) and tensile bond strength (TBS), considering surface pretreatments and bonding agents after 24h and thermocycling. RESULTS A total of 235 relevant titles and abstracts were found, yielding 11 final selections. Low risk of bias was observed in most studies. For polyetheretherketone (PEEK) specimens, random-effect models showed that, compared to non-treated controls, pretreatments associated with Visio.link® (Bredent, Senden, GE) increased TBS by 26.72MPa (95% confidence interval (CI), 19.69-33.76; p<0.00001) and increased SBS by 4.86MPa (95% CI, 2.61-7.10; p<0.00001). Air abrasion improved SBS by 4.90MPa (95% CI, 3.90-5.90; p<0.00001) (50 m alumina) and 4.51MPa (95% CI, 1.85-7.18; p=0.0009) (silica-coated CoJet). In comparison to non-treated controls, Visio.link® and Signum PEEK Bond® (Heraeus Kulzer, Hanau, GE) increased SBS by 33.76MPa (95% CI, 18.72-48.81; p<0.00001) and 33.28MPa (95% CI, 17.48-49.07; p<0.00001), respectively. No differences were found between Visio.link® and Signum PEEK Bond® or Monobond Plus/Heliobond® (Ivoclar Vivadent, Schaan, LH) (p>0.05). Similar results were observed for polyetherketoneketone (PEKK) specimens. SIGNIFICANCE This review shows improved HPP bonding following the application of various surface pretreatments, including air abrasion and bonding agents.

DOI: https://doi.org/10.1016/j.dental.2020.01.002

Originally published at:
Gama, Lorena Tavares; Duque, Thais Mageste; Özcan, Mutlu; Philippi, Analucia Gebler; Mezzomo, Luis André Mendonça; Gonçalves, Thais Marques Simek Vega (2020). Adhesion to high-performance polymers applied in dentistry: A systematic review. Dental Materials, 36(4):e93-e108.
DOI: https://doi.org/10.1016/j.dental.2020.01.002

Adhesion to high-performance polymers applied in dentistry: a systematic review

Short Title: Polymer bonding review

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Acknowledgments

Special thanks are due to Maria Gorete Monteguti Savi, librarian of the Federal University of Santa Catarina, for her help.

Declaration of Interest statement

The authors report no conflicts of interest.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Abstract

The aim of this systemic review, conducted in accordance with the PRISMA statement, was to investigate the impact of surface pretreatments on the bonding strength of high-performance polymers (HPPs). Eight databases were searched through March 2019. Risk of bias was assessed and random effects meta-analyses were applied to analyze mean differences in shear bond strength (SBS) and tensile bond strength (TBS), considering surface pretreatments and bonding agents after 24 h and thermocycling. A total of 235 relevant titles and abstracts were found, yielding 11 final selections. Low risk of bias was observed in most studies. For polyetheretherketone (PEEK) specimens, random-effect models showed that, compared to non-treated controls, pretreatments associated with Visio.link® (Bredent, Senden, GE) increased TBS by 26.72 MPa [95% confidence interval (CI), 19.69–33.76; $p < .00001$] and increased SBS by 4.86 MPa (95% CI, 2.61–7.10; $p < 0.00001$). Air abrasion improved SBS by 4.90 MPa (95% CI, 3.90–5.90; $p < 0.00001$) (50 µm alumina) and 4.51 MPa (95% CI, 1.85–7.18; $p = 0.0009$) (silica-coated CoJet). In comparison to non-treated controls, Visio.link® and Signum PEEK Bond® (Heraeus Kulzer, Hanau, GE) increased SBS by 33.76 MPa (95% CI, 18.72–48.81]; $p < 0.00001$) and 33.28 MPa (95% CI, 17.48–49.07]; $p < 0.00001$), respectively. No differences were found between Visio.link® and Signum PEEK Bond® or Monobond Plus/Heliobond® (Ivoclar Vivadent, Schaan, LH) ($p > 0.05$). Similar results were observed for polyetherketoneketone (PEKK) specimens. This review shows improved HPP bonding following the application of various surface pretreatments.

KEY WORDS: adhesives; esthetic dentistry; polymer; material science; polyetheretherketone; polyetherketoneketone; systematic review.

1. Introduction

High-performance polymers (HPPs) [1, 2] are semi-crystalline thermoplastic materials consisting of aromatic benzene molecules connected by functional ether or ketone groups, resulting in different combinations of polyaryletherketones [3, 4]. Polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) are commonly used HPPs, especially in dental applications [2]. There is great interest and ongoing research in tissue-substitute materials that have human bone-like mechanical characteristics. In this context, HPPs may help meet patient demands for metal-free dental reconstructions owing to their biocompatibility and their mechanical properties of heat resistance, solvent resistance, excellent electrical insulation, and robust wear and fatigue resistances [5, 6]. In addition, the natural radiolucency of HPPs makes prostheses made of them amenable to diagnostic imaging, such as computed tomography, magnetic resonance imaging, and x-ray, with less artifact interference than metal-based restorations [5]. These properties make HPPs an attractive alternative to ceramic and metal for restorations.

HPPs are used for many dental applications, including transitional and healing abutments [7], dental implants [8], dental clasps [9], and as alternative rigid materials for removable partial denture prosthesis frameworks [9] and fixed dental prostheses [10]. HPP devices can be formed in thermo-pressing procedures (e.g. BioHPP®, Bredent, and Senden products) or milled with computer-aided design/ manufacturing techniques (e.g. Juvora Dental Disc® products) [11].

Because of the low translucency and greyish or pearl-white opaque color of HPPs, these materials are not suitable for monolithic esthetic dental restorations,[10] requiring a resin-composite surface veneer to achieve satisfactory aesthetics [1]. Furthermore, their chemical inertness, low surface energy, and resistance to surface modification has made it difficult to bond materials to HPP materials, which may explain, at least part, why HPPs are not yet commonly used in restorative and prosthetic dentistry [6, 12]. HPP surface property modification has become a research hotspot with the goal of increasing HPP surface free energy and thus HPP bonding performance [5, 6, 11, 12].

There are two highly regarded surface treatment classes: mechanical and chemical. Mechanical treatments include airborne-particle (silica or aluminum oxide) abrasion, laser and plasma applications, and bur grinding. Chemical treatments include etching with sulfuric acid and Piranha solution as well as the application of adhesive primers, such as Visio.link® (Bredent, Senden, GE) and Signum PEEK Bond® (Heraeus Kulzer, Hanau, GE) [10, 13, 14]. Surface treatments, especially chemical etching and mechanical roughness induction, are thought to improve material adhesiveness by diversifying functional groups [14]. Sulfuric acid has been shown to increase surface porosity and permeability, thereby facilitating mechanical bonding without resin tag formation [12]. Conversely, plasma treatment increases material wettability, thereby increasing the bond strength potential of HPPs with resin materials [5].

Knowledge concerning the potential and limitations of each treatment, with its particular specific effects, is limited and a standard protocol for enhancing HPP dental prostheses is lacking. From a clinical perspective, the use of caustic solutions (e.g. sulfuric acid or piranha solution) for chair-side HPP frameworks and abutments would be hazardous and should be avoided or restricted. The purpose of this study was to investigate the impact of different surface conditioning methods and adhesion promoters on the strength of veneering composite resin bonding to common HPPs, namely PEEK and PEKK. Secondarily, postconditioning bonding durability was analyzed. We tested the null hypothesis that resin-HPP bonding and durability are not affected by PEEK/PEKK prebonding treatments.

2. Materials and methods

2.1 Eligibility criteria

This systematic review was structured in accordance with PRISMA (Preferred Reporting Items for Systematic Review and Meta Analyses Protocols) [15] and the PRISMA checklist [16]. The PICOS framework applied was: Population, HPP specimens; Intervention, surface pretreatment and bonding agent application; Comparison, untreated specimens; Outcomes, tensile bond strength (TBS) and shear bond strength (SBS); and Study design, in vitro studies. The addressed focused question was: “Does surface pretreatments and/or bonding agent application impact the bond strength between composite veneering resin and HPP?”

Studies evaluating the ability of surface treatments to improve HPP bonding strength for dental applications were included to this review. No publication time or language restrictions were applied. There were five exclusion criteria for collated studies: a) HPP was not used for a dental purpose; b) surface treatments were not applied or compared; c) no analysis of a control group [untreated specimens or omission of bonding agent recommended by the manufacturer (Visio.link® or Signum PEEK Bond®)]; d) bonding strength not measured or results not presented in MPa; e) <5 specimens per subgroup; f) publication type is review, letter, abstract, opinion, case report/series, or book chapter.

2.2 Information sources and search strategy

The search was elaborated using combinations of terms that were adapted for each of the following electronic databases: Embase, Latin American and Caribbean Health Sciences, PubMed, SCOPUS, and Web of Science. In addition, a grey literature search was conducted on Google Scholar, Open Grey, and ProQuest. The searches were conducted from database inception through the search performance date, which was September 17, 2018 . An update was performed in March 15, 2019 (Supplementary Table 1).

Following the recommendation by Greenhalgh and Peacock [17], reference lists of included studies were hand-searched to find additional potentially relevant references.

Reference management and removal of duplicates were performed in EndNote X8 software (Thomson Reuters, Philadelphia, USA).

2.3 Study selection

Studies were selected in two phases. In phase one, two reviewers (authors L. T. G. and T. M. D.) screened titles and abstracts independently to identify eligible studies. In phase two, collated studies identified as potentially eligible were subjected to a full-text reading. Doubt or discrepancies were solved by consensus and discussion with the third reviewer (A. G. P.). In both phases, a team of three experts (M. O., A. G. P., and L. A. M. M.) crosschecked all of the information. If any disagreement remained regarding eligibility, it was discussed between the research team and the coordinator (T. M. S. V. G.).

2.4 Data extraction

Data extracted from included papers were registered independently by two researchers (L. T. G. and T. M. D.), tabulating data of interest in an Excel spreadsheet (Microsoft Corporation, Redmond, USA). HPP specimen characteristics, the number of specimens examined, the veneering composite(s) applied, surface roughness, type of bonding strength test applied (TBS or SBS), type of surface pretreatment, and main conclusions described in the papers were recorded (Table 1).

2.5 Statistical analysis

Results were combined for meta-analysis based on Mantel-Haenszel analyses. Heterogeneity was determined by calculating I^2 values. Mean differences were evaluated between continuous outcomes (i.e. effect of each surface treatment on TBS and SBS). The meta-analysis was conducted Review Manager® (version 5.3; The Cochrane Collaboration, London, UK) with the significance level set at 5%.

2.6 Assessment of risk of bias

We evaluated methodological quality with the use of a clinical appraisal checklist for experimental studies by the Joanna Briggs Institute [18] that had been adapted for another systematic review of *in vitro* studies [19]. Two reviewers (L.T.G. and A.G.P.) assessed and scored the articles independently. Each study was classified as Low risk (bias, if present, is unlikely to alter the results seriously), Unclear risk (a risk of bias that raises some doubt about the results, or High risk (bias may alter the results seriously).

3. Results

3.1 Search and selection

The search strategy details are illustrated in a PRISMA flowchart (Fig. 1). The systematic database searches yielded 235 potentially relevant titles and abstracts. The grey literature search identified another 100 studies. After removal of duplicates, 146 records remained, 10 of which were selected for full-text screening. One additional article was included from the hand-search. Thus, a total of 11 selected articles were included in the qualitative synthesis (Table 1); quantitative analysis was performed with data from 8 of the 11 selected articles (Figs. 3 to 7). Strong inter-examiner agreement was obtained during full-text screening and article final selection (Cohen's Kappa, 0.84).

3.2 Risk of bias

All 11 eligible studies were *in vitro* studies that were well-designed and found to have a low risk of bias for all criteria, except for the multiple measurements concern. Seven studies [4, 20-25] evaluated the bonding interface only once (after thermocycling or after 24 h), which reduced their level of evidence and increased their risk of bias accordingly (Fig. 2).

3.3 Study characteristics

The characteristics of the included studies are summarized in Table 1. Their publication years ranged from 2013 to 2019. A total of 5,066 specimens were analyzed. The brands of HPP used for specimen manufacture were: PEEK BreCAM Bio HPP® (Bredent, Senden, GE) [4, 21], PEEK Juvora Dental Disk® (Juvora, Lancashire, UK) [20, 24], Vestakeep DC4420® (Evonik Industries, Essen, GE) [20, 24], Vestakeep DC4450® (Evonik Industries) [20, 24], PEEK Dentokeep® (NT-trading, Karlsruhe, GE) [10, 22, 26], Pekkton Ivory® (Cendres+Métaux, Biel, SW) [23, 27, 28], and Tizian PEEK® (Schütz Dental, Rosbach, GE) [25].

Specimen size varied depending on the tests performed, with most specimens having a cylindrical shape (Table 1). The following commercial veneer brands were used: Crea.lign® Paste and Opaker (Bredent, Senden, GE) [4], Combo.lign® (Bredent, Senden, GE) [21], Nexco® (Ivoclar Vivadent, Schaan, LH) [27], VITA VM LC® (Vita, Postfach, GE) [10, 20, 24, 26], GC Gradia® (GC Europe, Leuven, BE) [10, 20], GC Gradia Direct Flo® (GC Europe) [20], Signum Composite® (Heraus Kulzer, Hanau, GE) [22], Signum Ceramis® (Heraus Kulzer, Hanau, GE) [22], Filtek Z350 XT® (3M ESPE, St. Paul, USA) [23], Sinfony® (3M ESPE, St. Paul, USA) [10, 26], Anaxblend® Dentin and Opaquer Paste (Anaxdent, Ardmore, USA) [28], and Dialog Occlusal® (Schütz Dental, Rosbach, GE) [25].

3.4 Qualitative analysis of the surface treatment protocols

A great variety of conditioning protocols, encompassing some 163 different methods, were described (Table 1). The analysis considered type of bonding analysis (TBS or SBS); the use of specimen aging; surface pretreatment; and the bonding system evaluated.

For bonding strength assessment, SBS and TBS were applied in 5 studies [4, 20, 21, 23, 24], and 6 studies [10, 22, 25-28], respectively. Material failures were evaluated by optical [20] and digital [10, 28] microscopes, reflected light microscope [23, 26, 27], stereomicroscope [21, 28], or scanning electron microscopy [4, 22, 25, 28] with different magnifications. All studies applied one or more artificial method of aging. In seven studies [4, 10, 21, 22, 25, 27, 28] thermocycling was applied, and the number of cycles was set at 5,000 [4, 22], 7,000 [27], 10,000 [10, 21, 28], or 20,000 [25] at water temperatures varying from 5 °C to 55 °C. Water storage (37 °C) was also performed in 6 studies [10, 20, 23, 24, 26, 28], usually for 24 h, but for 60 d in one study [26].

All studies, except one [26], evaluated air abrasion pretreatment with aluminum oxide with different particles sizes (50–110 μm) and several pressure levels. Evaluated chemical pretreatments included sulfuric acid [21, 26, 27], piranha solution [22, 26], and acetone 99% [21]. Additional evaluated pretreatments were: silica-coating (CoJet® and Rocatec Systems®, 3M ESPE, St. Paul, USA) [21, 23, 25, 27], laser irradiation (YAG [4] or Yb:PL [21]), and plasma treatments (argon/oxygen [20, 24] and oxygen [20, 28]). The following pretreatment combinations were also performed: laser irradiation followed by air abrasion (50 μm alumina or silica-coated CoJet system®) [4]; air abrasion (100 μm alumina) followed by plasma treatment (oxygen or argon/oxygen) [20, 24, 28] air abrasion (50 μm alumina) followed by piranha solution [22], and sulfuric acid followed by air abrasion (110 μm silica-coated alumina, Rocatec Plus®) [27].

3.5 Quantitative analysis of surface treatment protocols

3.5.1 PEEK

3.5.1.1 Surface pretreatments

An initial meta-analysis was performed to compare surface pretreatments and TBS (Fig. 3). Visio.link® bonding agent was applied in all 11 studies, and a negative control group (bonding agent used without a pretreatment) was also applied in 2 studies [10, 26]. According to a random-effect model, the application of any pretreatment, associated with Visio.link®, increased TBS by an average of 26.72 MPa (95% CI: 19.69–33.76; $p < 0.00001$)

(Fig. 3.1), even after thermocycling. Although different pretreatments were described, air abrasion was performed with a similar methodology across studies, allowing data analysis. The application of air abrasion, associated with Visio.link®, improved TBS by an average of 33.76 MPa (95%CI: 18.72–48.81; $p < 0.00001$) (Fig. 3.2).

A second meta-analysis was performed that considered SBS of specimens subjected to surface treatments after thermocycling (Fig. 4). Visio.link® was the standardized bonding agent and no pretreatment negative controls were included in 2 studies [4, 21]. Combined together, the application of any pretreatment yielded a significant 4.86 MPa increase in SBS (95% CI, 2.61–7.10; $p < 0.00001$) compared to the SBS of untreated controls (Fig. 4.1). Of the various mechanical and chemical pretreatments employed in the included studies, only air abrasion was applied with similar methodologies between studies, thus allowing metanalysis. We found that the application of air abrasion (50 μm alumina) improved SBS by an average of 4.90 MPa (95% CI, 3.90–5.90; $p < 0.00001$) (Fig. 4.2). Likewise, silica-coated air abrasion (CoJet system®) increased SBS by an average of 4.5 MPa (95% CI, 1.85–7.18; $p = 0.0009$) (Fig. 4.3).

3.5.1.2 Bonding agents

Unfortunately, no studies compared SBS across specimens with different bonding agents following a similar methodology, making it difficult to carry out a metanalysis. Two studies [10, 22] that measured TBS evaluated bonding strength of PEEK surfaces with a similar pretreatment (Air abrasion, 50 μm alumina) after thermocycling (Fig. 5). A random-effect model showed significantly increased TBS after bonding agent application, compared to untreated controls, with mean differences of 33.76 MPa (95% CI, 18.72–48.81; $p < 0.00001$) and 33.28 MPa (95% CI, 17.48–49.07; $p < 0.00001$) for Visio.link® and Signum PEEK Bond®, respectively (Fig. 5.1 and 5.2).

An additional meta-analysis was performed to compare bonding agents different from that recommended by the manufacturer (Visio.link® control) (Fig. 6). Only studies that applied air abrasion (50 μm alumina powder) and thermocycling aged specimens were considered for standardization purposes [10, 22, 26]. When bonding agents were analyzed together, the random-effect model showed higher TBS in favor to the Visio.link® group, with a mean difference of -1.85 MPa (95% CI, -2.51– -1.18; $p < 0.00001$) (Fig. 6.1). TBS did not differ significantly between specimens bonded with Visio.link® and specimens bonded with Signum PEEK Bond® (Fig. 6.2) or Monobond Plus/Heliobond® (Ivoclar Vivadent, Schaan, LH) (Fig. 6.3).

3.5.2 Modified PEEK

Pigments and titanium oxide (TiO_2)-containing powders have been added to PEEK to improve its native opacity. It is unclear if such pigments influence surface bonding strength. Previous studies [20, 24] compared the SBS of an unfilled regular PEEK Juvora Dental Disk® (Juvora) to two modified PEEKs, one containing 20% TiO_2 powder (Vestakeep DC4420®) and the other containing 20% TiO_2 powder and 1% of pigment powder (Vestakeep DC4450®). As the main purpose of the study was to investigate the influence of argon-oxygen low-pressure plasma treatment on SBS, all specimens were pretreated with air abrasion (100 μm alumina) and bonding agent (Visio.link®) to standardize the experiment. According to results, a significantly increase of SBS ($p < 0.00001$), in favor to the experimental groups (plasma treatment), was observed for all specimens, except for Vestakeep DC4450® group, where the impact of plasma application was not significant (p = 0.89) (Fig. 7.3). Compared to control specimens, the use of air abrasion and plasma increased SBS significantly, by an average of 5.74 MPa for PEEK Juvora Dental Disk® (95% CI, 3.24–8.24; $p < 0.00001$) and an average of 13.49 MPa (95% CI, 11.65–15.33; $p < 0.00001$) for Vestakeep DC4420® reinforced PEEK (Fig. 7.1 and 7.2).

3.5.3 PEKK

There were three studies that used PEKK [23, 27, 28], but their methodological heterogeneity made them not well-suited for quantitative data analysis. Regarding mechanical testing, one study evaluated SBS across three surface treatments (sulfuric acid 95% vs. air abrasion with 50 µm alumina or 110 µm silica-coated alumina) [23]. Several bonding agents [Visio.link®, Luxatemp Glaze & Bond® (DMG, Hamburg, GE), Single Bond Universal® (3M ESPE, St. Paul, USA), All-Bond Universal® (BISCO, Schaumburg, USA and Monobond Plus/Heliobond®) were tested. Composite Filtek Z350 XT® (3M ESPE, St. Paul, USA) was applied to all specimens, after which they were stored in water for 24 h at 37 °C. Our analysis indicated that air abrasion increased bonding strength more efficiently than sulfuric acid 95% (p < .0001). When comparing bonding agents, silane containing self-etching universal adhesive (Single Bond Universal®) showed similar SBS values of Visio.link®, regardless of the pretreatment applied. The combination of air-abrasion with 10-methacryloyloxydecyl dihydrogen phosphate-containing (All-Bond Universal® or Single Bond Universal®) or methylmethacrylate (MMA)-containing (Luxatemp Glaze & Bond®, Visio.link®, or Monobond Plus/Heliobond®) bond materials has been recommended for bonding resin composites to PEKK materials [23].

In the remaining studies [27, 28], TBS was used to analyze PEKK bonding strength. In one study [27], the bonding interface was compared across four pretreatment groups: control (no pretreatment); air abrasion (110 µm alumina powder) (Group Al); 98% sulfuric acid etching (Group SA); tribochemical silica-coating (Rocatec Plus®, 110 µm at 2 bar for 10 s) (Group Trib); and sulfuric acid etching followed by tribochemical silica-coated (Group SATrib). For bonding, the silane coupling agent Monobond-S® (Ivoclar Vivadent, Schaan, LH) was applied, followed by Visio.link®. Half of the specimens were tested after being stored in water for 24 h at 37 °C; the other half were submitted to thermocycling (5 °C/55

°C, 7,000×). Surface morphology and chemical elements of the treated surfaces were also evaluated by EDX analysis. All four treatments had an augmenting effect on PEKK surface roughness. The presence of silica was detectable on the silica-coated surfaces in the Trib and SATrib groups. No group differences were found before thermal cycling. Groups Trib and SATrib specimens showed significantly increased TBS after thermocycling. Furthermore, Groups SA, Trib and SATrib illustrated an increase of Weibull moduli after thermocycling, but decrease was observed in Groups C and Al. The authors explained that silanization seemed to produce more hydrolytically stable PEKK/resin composite bonds with methacrylate-based veneering resin. The SATrib pretreatment emerged as the best surface treatment for bonding veneer resin to PEKK-based dental restorations.

The second study [28] that evaluated the TBS of PEKK included an analysis of the bonding of MMA and dimethacrylate (DMA)-based polymers to PEKK. The specimens were pretreated with air abrasion (100 µm alumina) and subjected to a plasma treatment (Oxygen, 15 s, 20 W). Two bonding agents (Visio.link® and PEKK Bond PB®, Anaxdent, Ardmore, USA) were compared. The DMA-based polymers (Anaxdent® dentin, flowable or conventional, and opaquer paste) were tested after storage in water for 24 h at 37 °C. Twenty specimens of each subgroup were thermocycled (5°C/55°C, 10,000×) before TBS analysis. TBS was most influenced by the bonding agent, followed by the bonding polymer type (MMA vs. DMA), aging via thermocycling, and the opaquer layer [28]. Use of Visio.link® resulted in greater TBS to PEKK than did PEKK Bond®. The MMA-based denture acrylic polymer resulted in greater TBS to PEKK than did the DMA-based veneering composite. Flowable veneering composite, opaque layer, and oxygen plasma pretreatment in combination with the bonding agent also increased TBS. The authors concluded that sufficient bonding to PEKK is possible when a plasma treatment is used in combination with bonding agents and an opaquer layer [28].

4. Discussion

Although HPPs have good mechanical properties, their inert surfaces require surface conditioning due to otherwise poor adherence to veneering resin materials [10, 28]. The scarcity of literature related to HPP bonding quality and durability has precluded the establishment of an efficient HPP surface conditioning protocol, especially for dentistry applications. This systematic review is the first to analyze pooled data to assess the influence of different surface conditioning and bonding procedures on the bonding strength of HPPs with veneering resin composites. The null hypothesis was rejected because surface conditioning procedures did increase the bonding strength of HPP to veneering resin composite significantly, even after thermocycling.

In this review, only *in vitro* studies were included because no clinical evidence was available. The experimental studies were, in general, well designed and well controlled studies with a low risk of bias, increasing confidence related to both methodological quality and the results presented. However, the risk of bias was increased due to specimens being analyzed only once in three studies (after thermocycling or after 24 hours)[4, 20-25]. Methodological differences between the selected studies also contributed to a high heterogeneity in the meta-analysis. Consequently, the results should be interpreted with caution.

In general, our meta-analysis results showed that, compared to non-treated controls, surface pretreatments performed before bonding agent application improved HPP bonding strength. In particular, combining mechanical and chemical pretreatments (e.g. air abrasion, piranha solution, or sulfuric acid associated with Visio.link®) improved TBS even after thermocycling. Similar results have been reported in previous studies [1, 4, 12, 29]. Meanwhile, surface abrasion with 50 μm alumina followed by Visio.link® bonding increased TBS. Air abrasion increases surface roughness while removing organic contaminants from the surface, creating a fresh, active surface layer [4]. It also promotes micromechanical interlocking of polymer-based dental materials and enables the bonding agent to better penetrate them, resulting in a micro-mechanical retention and, presumably, an increased surface bonding capacity [6, 26].

Although a quantitative meta-analysis could not be performed for chemical conditioning (Piranha solution or sulfuric acid) due to there being an insufficient amount of data, improved bonding strength of PEEK was reported relative to non-treated controls. According to Schmidlin et al., sulfuric acid acts on the carbonyl and ether groups of PEEK; meanwhile, Piranha solution oxidizes PEEK, increasing the surface polarity by opening aromatic rings, which generates additional functional groups that can react readily with bonding agents and thereby improve bond strength [12].

Regarding SBS analysis of surface pretreatments, only studies in which Visio.link was used were included in the meta-analysis so that the bonding agent would be standardized and, consequently, reduce bias (Fig. 4) [4, 21]. Although SBS value differences were less pronounced than TBS values, SBS data reflected similar performance improvements following pretreatments compared to non-treated specimens. Air abrasion, in particular, improved SBS, and these results are in agreement with a previous study [29], though a resin cement was evaluated instead of veneering resins in that study.

Our meta-analysis focused on silica-coated (CoJet System® and Rocatec®) air abrasion (Fig. 4.3) revealed that, when associated with Visio.link®, the application of silica-coated systems improved SBS by 4.51 MPa (95% CI, 1.85–7.18; $p = 0.0009$). Although similar positive effects of these pretreatments have been reported previously [30, 31], others have reported that silica-coating pretreatments can reduce PEEK bonding strength [12, 13]. In one scanning electronic microscopy study [11], in which silica-coating was shown to create irregularities on the PEEK surface and enhance the initial bonding with veneering resin materials, the authors argued that the presence of residual submicron particles of silica on the PEEK surface might jeopardize long-term PEEK adhesion and that methodological differences affecting silica residua may thus help to explain discordant results between different studies.

Four of the presently reviewed studies [4, 20, 21, 28] evaluated the use of laser and plasma applications as HPP pretreatments, but a meta-analysis was not performed because the methodologies used differed considerably across the studies. Although laser treatment (Er:YAG) was reported to increase surface roughness, no significant effect on veneering composite bond strength was found [4]. Caglar and Duymus [29] suggested that this lack of effect on bond strength may be related to the observation that laser-treated PEEK surfaces have a complicated structure with pits that are deep but too narrow to allow the easy flow of resin.

Comparing the effects on TBS of different PEEK bonding materials revealed a slight superiority of Visio.link® over Signum PEEK bond® (mean difference of -1.85 MPa, $I^2 = 93\%$, $p < 0.0001$) (Fig. 5.1) but not over Signum PEEK Bond® or Monobond Plus/Heliobond® (Figs. 5.2 and 5.3). In contrast, Caglar and Duymus [29] reported that Visio.link® produced greater SBS than Signum PEEK Bond® ($p < 0.05$) and attributed the differing performance of two systems to the chemical compositions of the products [29]. Signum PEEK Bond® contains MMA and bifunctional monomers on a phosphoric acid ester base, whereas the main constituents of Visio.link® are MMA and pentaerythritol triacrylate [29], the latter of which has a high capacity to modify PEEK surfaces and, consequently, to improve bonding strength efficiently. Notwithstanding, two previous studies [26, 32] reported similar outcomes for bond strength with the use of Visio.link® versus Signum PEEK Bond®. Methodological differences regarding pretreatment conditioning and bonding protocols may contribute to differences in results between studies. For instance, the use of self-adhesive resin cement instead of a veneering resin in Caglar and Duymus' study [29] might help to explain why they observed a stronger bonding with Visio.link® than with Signum PEEK Bond®.

Pigments and TiO_2 powder have been added to PEEK to improve the flexure resistance and esthetic appearance of the final material. Thus, an additional analysis was performed to compare the influence of plasma treatment on the bonding of modified versus unmodified PEEK (Fig. 7). The application of argon/oxygen low-pressure plasma with air abrasion and Visio.link® bonding increased SBS ($p < 0.00001$) of both regular PEEK Dental Disk® (Juvora, Lancashire, UK) and PEEK containing TiO_2 (Vestakeep DC4420®), but did not increase SBS of PEEK modified by TiO_2 and pigments significantly (Vestakeep DC4450®; $p = 0.89$).

Widely used types of plasma in the surface treatment of polymer materials include nitrogen, oxygen, argon, and hydrogen [6]. Typically, plasma treatment encompasses surface cleaning, micro-etching, surface activation, and ablation [13]. Because plasma treatment decreases the surface roughness of PEEK, its positive effect on SBS might be related to a chemical interaction. Low-temperature plasma increases free surface energy, increasing material wettability and the formation of functional groups on PEEK surfaces [7, 24]. Ultimately, low-temperature plasma treatment can transform a non-polar surface into a polar surface, producing a dense cross-linked layer that increases material interactions with a bonding agent and, consequently, improves SBS (Figs. 7.1 and 7.2). However, the inclusion of additional pigments seems to reduce the pro-bonding influence of plasma treatment, though more studies are required to evaluate the long-term performance of plasma-treated polymer materials.

Three of the studies included in this review [23, 27, 28] analyzed the bonding strength of PEKK specimens, but important methodological differences did not allow us to conduct a meta-analysis of their results. Notwithstanding, SBS analysis of PEKK specimens has shown that mechanical pretreatments increase bonding strength more efficiently than a chemical pretreatment (95% sulfuric acid) ($p < 0.0001$). Although PEKK has more carbonyl groups than PEEK, resulting in greater carbonyl group breakage [33], its SBS can still be improved by increasing surface roughness with air abrasion. Combining air-abrasion with bonding agents containing 10-methacryloyloxydecyl dihydrogen phosphate (All-Bond Universal® and Single Bond Universal®) or MMA (Luxatemp Glaze & Bond®, Visio.link®, Monobond Plus/Heliobond®) has also been recommended to improve bonding strength between resin composite and PEKK materials [23].

Regarding TBS analysis of PEKK bonding, an interesting recent study [27] revealed that tribochemical silica-coating (Rocatec®) with 98% sulfuric acid etching can provide an optimal PEKK surface treatment in preparation for resin veneering. This promising result might be related to remnant silica particles left in silica-coated PEKK surfaces following the use of a silane coupling agent. The authors indicated that silanization produced particularly hydrolytically stable PEKK/resin composite bonds with methacrylate-based veneering resin [27].

It is important to emphasize that pretreatment alone is not sufficient to guarantee long-term stable bonding of veneering resin to PEEK surfaces [11]. Minimal bond strength can be achieved without a bonding agent [5, 10, 21, 26], as evidenced by comparisons of bonding between non-treated control specimens versus specimens subjected to any pretreatment in association with a bonding agent [mean difference of 33.76 MPa (95% CI, 18.72–48.81 for Visio.link® and 33.28 MPa (95% CI, 17.48–49.07) for Signum PEEK Bond®). According to ISO 10477, 5 Mpa is the minimum acceptable bonding strength of resin-based materials [29]. However, it has been suggested that at least 10~12 MPa should be required in oral conditions to ensure durable bonding between resin-based materials [13]. In the present review, the association of surface pretreatment and bonding agent significantly increased bonding strength, with values acceptable according to ISO 10477 standards. Our results reinforce the notion that HPP dental prostheses must be treated with a mechanical and/or chemical method and that such treatment should be administered in combination with a bonding agent to establish a suitably durable adhesiveness between HPP and veneering resins.

The limitations of this systematic review include methodological differences, differing types of specimen aging, and a lack of clinical studies, Consequently, further studies are necessary to establish a clinical HPP adhesive protocol for long-term bonding stability.

5. Conclusions

Bonding strength between HPP and veneering resin composite increases significantly when a surface pretreatment is administered in association with a bonding system, especially when PEEK is used. For PEKK surfaces, tribochemical silica-coating applied in association with 98% sulfuric acid etching seems to be the best way to strengthen bonding to resin veneering. Given the methodological differences among existing studies and the general lack of clinical studies in this field, we encourage further clinical research in HPP bonding long-term analysis.

Funding

The authors report no conflicts of interest and no financial support for this study.

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Figures

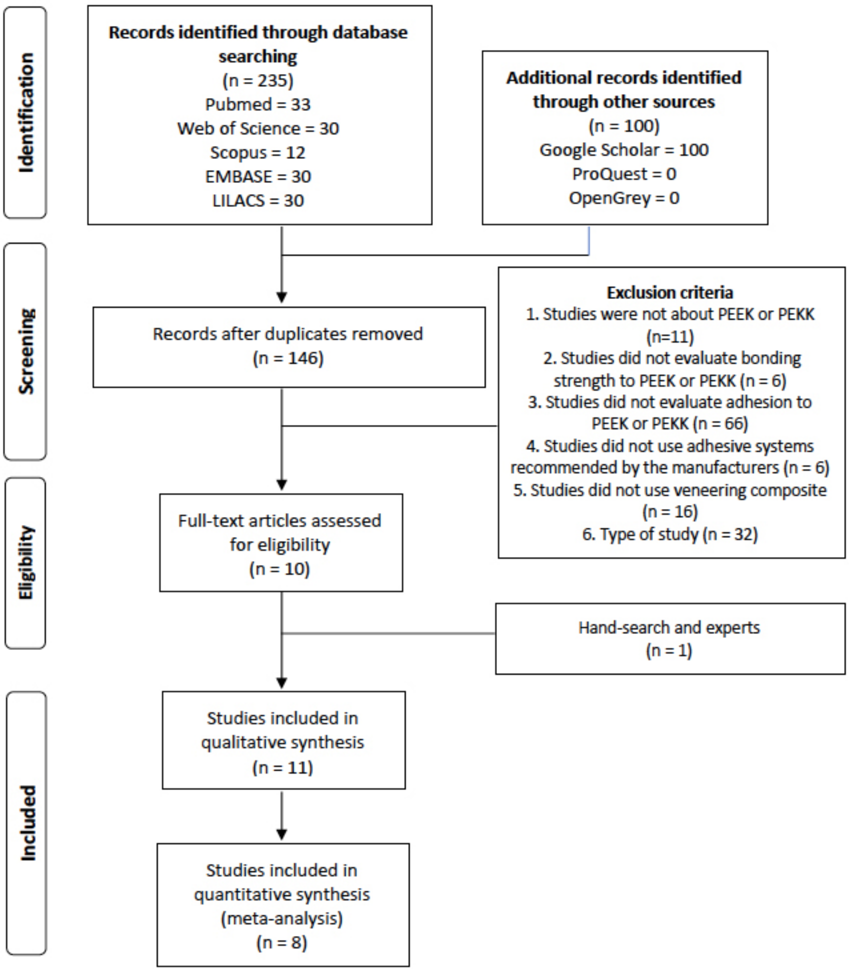


Figure 1. Flowchart of the study screening and selection process.

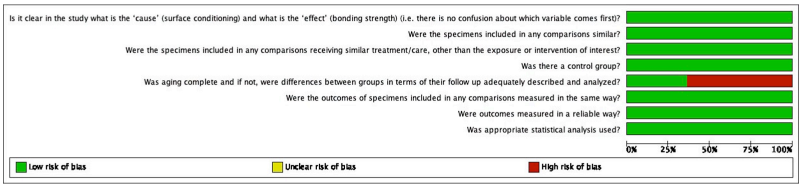


Figure 2. Bias risk assessment for included studies.

3.1 Experimental group: Different pretreatments* and Control group: Untreated

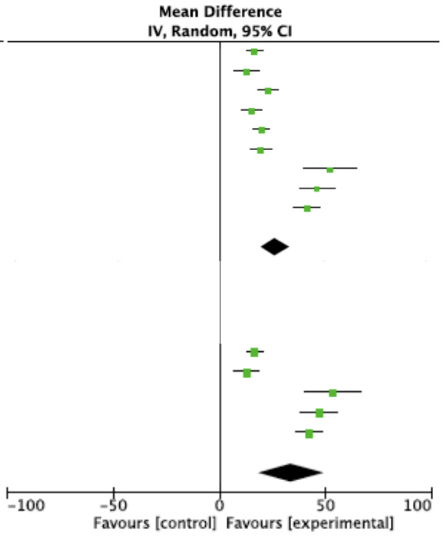
Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Keul, 2014 (G1Aa)	16.5	8	16	0.001	0.001	16	11.9%	16.50 [12.58, 20.42]
Keul, 2014 (G1Ab)	12.8	12.1	16	0.001	0.001	16	11.3%	12.80 [6.87, 18.73]
Keul, 2014 (G2Aa)	23.4	9.9	16	0.001	0.001	16	11.6%	23.40 [18.55, 28.25]
Keul, 2014 (G2Ab)	15.2	10.6	16	0.001	0.001	16	11.5%	15.20 [10.01, 20.39]
Keul, 2014 (G3Aa)	19.9	8	16	0.001	0.001	16	11.9%	19.90 [15.98, 23.82]
Keul, 2014 (G3Ab)	19.7	10.6	16	0.001	0.001	16	11.5%	19.70 [14.51, 24.89]
Stawarczyk, 2013 (G1Aa)	53.3	26.7	16	0.001	0.001	16	8.6%	53.30 [40.22, 66.38]
Stawarczyk, 2013 (G1Ab)	47	17.7	16	0.001	0.001	16	10.4%	47.00 [38.33, 55.67]
Stawarczyk, 2013 (G1Ac)	42.2	13.1	16	0.001	0.001	16	11.2%	42.20 [35.78, 48.62]
Total (95% CI)			**144**			**144**	**100.0%**	**26.72 [19.69, 33.76]**

Heterogeneity: $Tau^2 = 104.53$; $Chi^2 = 117.51$, df = 8 ($P < 0.00001$); $I^2 = 93\%$
Test for overall effect: Z = 7.45 ($P < 0.00001$)

3.2 Experimental group: Air abrasion* and Control group: Untreated

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Keul, 2014 (G1Aa)	16.5	8	16	0.001	0.001	16	20.9%	16.50 [12.58, 20.42]
Keul, 2014 (G1Ab)	12.8	12.1	16	0.001	0.001	16	20.5%	12.80 [6.87, 18.73]
Stawarczyk, 2013 (G1Aa)	53.3	26.7	16	0.001	0.001	16	18.3%	53.30 [40.22, 66.38]
Stawarczyk, 2013 (G1Ab)	47	17.7	16	0.001	0.001	16	19.8%	47.00 [38.33, 55.67]
Stawarczyk, 2013 (G1Ac)	42.2	13.1	16	0.001	0.001	16	20.4%	42.20 [35.78, 48.62]
Total (95% CI)			**80**			**80**	**100.0%**	**33.76 [18.72, 48.81]**

Heterogeneity: $Tau^2 = 277.81$; $Chi^2 = 104.59$, df = 4 ($P < 0.00001$); $I^2 = 96\%$
Test for overall effect: Z = 4.40 ($P < 0.0001$)



*** - All groups were treated with Visio.link;**

Figure 3. Meta-analysis of pretreatment effects on TBS, in MPa. Various pretreatments are compared together versus no-pretreatment controls in the upper section. Air abrasion pretreatment specifically was compared to no-pretreatment controls below.

4.1. Experimental group: Different pretreatments* and Control group: No pretreatment.*

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Ates, 2018 (G1Aa)	10.97	2.88	90	6.35	1.21	90	10.4%	4.62 [3.97, 5.27]
Ates, 2018 (G2Aa)	12.07	2.82	90	6.35	1.21	90	10.4%	5.72 [5.09, 6.35]
Ates, 2018 (G3Aa)	6.03	1.04	90	6.35	1.21	90	10.4%	−0.32 [−0.65, 0.01]
Ates, 2018 (G4Aa)	12.09	2.08	90	6.35	1.21	90	10.4%	5.74 [5.24, 6.24]
Ates, 2018 (G5Aa)	13.14	1.45	90	6.35	1.21	90	10.4%	6.79 [6.40, 7.18]
Çulhaoglu, 2017 (G1Aa)	8.07	2.54	11	5.09	2.14	11	9.7%	2.98 [1.02, 4.94]
Çulhaoglu, 2017 (G2Aa)	5.98	1.54	11	5.09	2.14	11	10.0%	0.89 [−0.67, 2.45]
Çulhaoglu, 2017 (G3Aa)	15.82	4.23	11	5.09	2.14	11	9.0%	10.73 [7.93, 13.53]
Çulhaoglu, 2017 (G4Aa)	10.81	3.06	11	5.09	2.14	11	9.5%	5.72 [3.51, 7.93]
Çulhaoglu, 2017 (G5Aa)	11.46	1.97	11	5.09	2.14	11	9.9%	6.37 [4.65, 8.09]
Total (95% CI)			**505**			**505**	**100.0%**	**4.86 [2.61, 7.10]**

Heterogeneity: $Tau^2 = 12.53$; $Chi^2 = 973.43$, $df = 9$ ($P < 0.00001$); $I^2 = 99\%$
Test for overall effect: $Z = 4.24$ ($P < 0.0001$)

4.2. Experimental group: Air abrasion* and Control group: No pretreatment.*

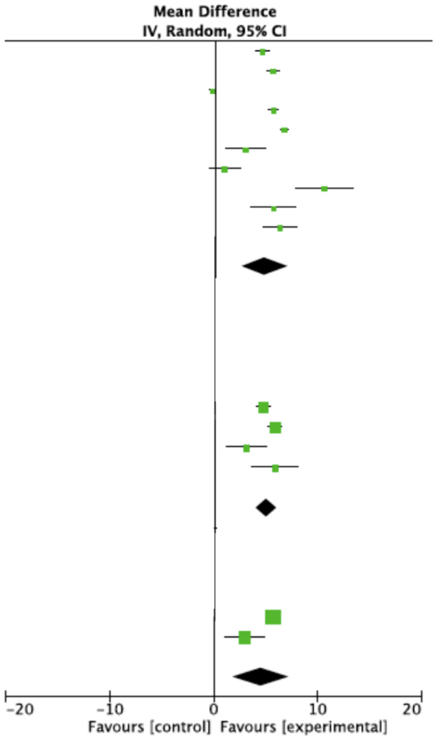
Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Ates, 2018 (G1Aa)	10.97	2.88	90	6.35	1.21	90	35.1%	4.62 [3.97, 5.27]
Ates, 2018 (G2Aa)	12.07	2.82	90	6.35	1.21	90	35.3%	5.72 [5.09, 6.35]
Çulhaoglu, 2017 (G1Aa)	8.07	2.54	11	5.09	2.14	11	15.9%	2.98 [1.02, 4.94]
Çulhaoglu, 2017 (G4Aa)	10.81	3.06	11	5.09	2.14	11	13.7%	5.72 [3.51, 7.93]
Total (95% CI)			**202**			**202**	**100.0%**	**4.90 [3.90, 5.90]**

Heterogeneity: $Tau^2 = 0.64$; $Chi^2 = 10.58$, $df = 3$ ($P = 0.01$); $I^2 = 72\%$
Test for overall effect: $Z = 9.58$ ($P < 0.00001$)

4.3. Experimental group: Air abrasion with silica* and Control group: No pretreatment.*

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Ates, 2018 (G2Aa)	12.07	2.82	90	6.35	1.21	90	56.0%	5.72 [5.09, 6.35]
Çulhaoglu, 2017 (G1Aa)	8.07	2.54	11	5.09	2.14	11	44.0%	2.98 [1.02, 4.94]
Total (95% CI)			**101**			**101**	**100.0%**	**4.51 [1.85, 7.18]**

Heterogeneity: $Tau^2 = 3.20$; $Chi^2 = 6.78$, $df = 1$ ($P = 0.009$); $I^2 = 85\%$
Test for overall effect: $Z = 3.32$ ($P = 0.0009$)



* - All groups were treated with Visio.link;

Figure 4. Meta-analysis of pretreatment effects on SBS, in MPa. Various pretreatments are compared together versus no-pretreatment controls in the upper section. Air abrasion and air abrasion with silica pretreatment specifically are compared to no-pretreatment controls in the middle and bottom sections, respectively.

5.1 Experimental group: Visio.link and Control group: Untreated

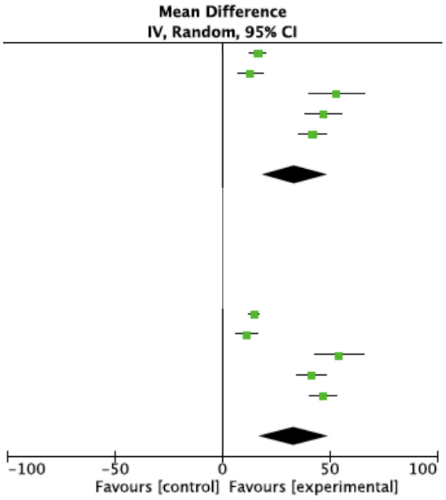
Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Keul, 2014 (G1Aa)	16.5	8	16	0.001	0.001	16	20.9%	16.50 [12.58, 20.42]
Keul, 2014 (G1Ab)	12.8	12.1	16	0.001	0.001	16	20.5%	12.80 [6.87, 18.73]
Stawarczyk, 2013 (G1Aa)	53.3	26.7	16	0.001	0.001	16	18.3%	53.30 [40.22, 66.38]
Stawarczyk, 2013 (G1Ab)	47	17.7	16	0.001	0.001	16	19.8%	47.00 [38.33, 55.67]
Stawarczyk, 2013 (G1Ac)	42.2	13.1	16	0.001	0.001	16	20.4%	42.20 [35.78, 48.62]
Total (95% CI)			**80**			**80**	**100.0%**	**33.76 [18.72, 48.81]**

Heterogeneity: $Tau^2 = 277.81$; $Chi^2 = 104.59$, df = 4 ($P < 0.00001$); $I^2 = 96\%$
Test for overall effect: Z = 4.40 ($P < 0.0001$)

5.2 Experimental group: Signum PEEK Bond and Control group: Untreated

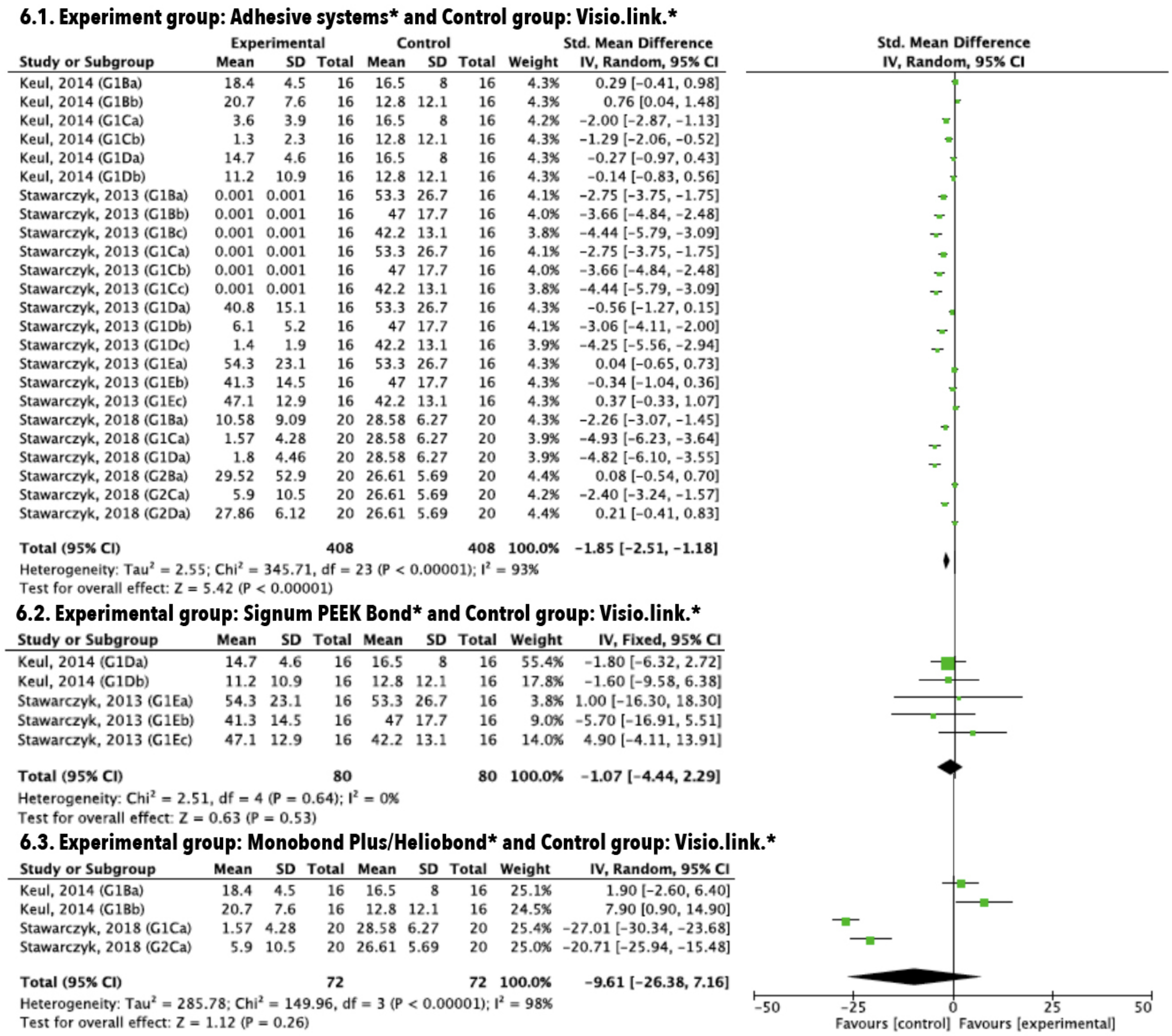
Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Keul, 2014 (G1Da)	14.7	4.6	16	0.001	0.001	16	20.7%	14.70 [12.45, 16.95]
Keul, 2014 (G1Db)	11.2	10.9	16	0.001	0.001	16	20.3%	11.20 [5.86, 16.54]
Stawarczyk, 2013 (G1Ea)	54.3	23.1	16	0.001	0.001	16	18.8%	54.30 [42.98, 65.62]
Stawarczyk, 2013 (G1Eb)	41.3	14.5	16	0.001	0.001	16	20.0%	41.30 [34.19, 48.40]
Stawarczyk, 2013 (G1Ec)	47.1	12.9	16	0.001	0.001	16	20.1%	47.10 [40.78, 53.42]
Total (95% CI)			**80**			**80**	**100.0%**	**33.28 [17.48, 49.07]**

Heterogeneity: $Tau^2 = 311.96$; $Chi^2 = 172.08$, df = 4 ($P < 0.00001$); $I^2 = 98\%$
Test for overall effect: Z = 4.13 ($P < 0.0001$)



*** - All groups were treated with Air Abrasion with 50 µm alumina powder;**

Figure 5. Meta-analysis of two predominant bonding agent effects on TBS, in MPa. The effects of Visio.link® and of Signum PEEK Bond® on bonding, relative to non-treated controls, are shown in the upper and lower parts of the figure, respectively.



6.1. Experiment group: Adhesive systems* and Control group: Visio.link.*

Study or Subgroup	Experimental Mean	SD	Total	Control Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Keul, 2014 (G1Ba)	18.4	4.5	16	16.5	8	16	4.3%	0.29 [−0.41, 0.98]
Keul, 2014 (G1Bb)	20.7	7.6	16	12.8	12.1	16	4.3%	0.76 [0.04, 1.48]
Keul, 2014 (G1Ca)	3.6	3.9	16	16.5	8	16	4.2%	−2.00 [−2.87, −1.13]
Keul, 2014 (G1Cb)	1.3	2.3	16	12.8	12.1	16	4.3%	−1.29 [−2.06, −0.52]
Keul, 2014 (G1Da)	14.7	4.6	16	16.5	8	16	4.3%	−0.27 [−0.97, 0.43]
Keul, 2014 (G1Db)	11.2	10.9	16	12.8	12.1	16	4.3%	−0.14 [−0.83, 0.56]
Stawarczyk, 2013 (G1Ba)	0.001	0.001	16	53.3	26.7	16	4.1%	−2.75 [−3.75, −1.75]
Stawarczyk, 2013 (G1Bb)	0.001	0.001	16	47	17.7	16	4.0%	−3.66 [−4.84, −2.48]
Stawarczyk, 2013 (G1Bc)	0.001	0.001	16	42.2	13.1	16	3.8%	−4.44 [−5.79, −3.09]
Stawarczyk, 2013 (G1Ca)	0.001	0.001	16	53.3	26.7	16	4.1%	−2.75 [−3.75, −1.75]
Stawarczyk, 2013 (G1Cb)	0.001	0.001	16	47	17.7	16	4.0%	−3.66 [−4.84, −2.48]
Stawarczyk, 2013 (G1Cc)	0.001	0.001	16	42.2	13.1	16	3.8%	−4.44 [−5.79, −3.09]
Stawarczyk, 2013 (G1Da)	40.8	15.1	16	53.3	26.7	16	4.3%	−0.56 [−1.27, 0.15]
Stawarczyk, 2013 (G1Db)	6.1	5.2	16	47	17.7	16	4.1%	−3.06 [−4.11, −2.00]
Stawarczyk, 2013 (G1Dc)	1.4	1.9	16	42.2	13.1	16	3.9%	−4.25 [−5.56, −2.94]
Stawarczyk, 2013 (G1Ea)	54.3	23.1	16	53.3	26.7	16	4.3%	0.04 [−0.65, 0.73]
Stawarczyk, 2013 (G1Eb)	41.3	14.5	16	47	17.7	16	4.3%	−0.34 [−1.04, 0.36]
Stawarczyk, 2013 (G1Ec)	47.1	12.9	16	42.2	13.1	16	4.3%	0.37 [−0.33, 1.07]
Stawarczyk, 2018 (G1Ba)	10.58	9.09	20	28.58	6.27	20	4.3%	−2.26 [−3.07, −1.45]
Stawarczyk, 2018 (G1Ca)	1.57	4.28	20	28.58	6.27	20	3.9%	−4.93 [−6.23, −3.64]
Stawarczyk, 2018 (G1Da)	1.8	4.46	20	28.58	6.27	20	3.9%	−4.82 [−6.10, −3.55]
Stawarczyk, 2018 (G2Ba)	29.52	52.9	20	26.61	5.69	20	4.4%	0.08 [−0.54, 0.70]
Stawarczyk, 2018 (G2Ca)	5.9	10.5	20	26.61	5.69	20	4.2%	−2.40 [−3.24, −1.57]
Stawarczyk, 2018 (G2Da)	27.86	6.12	20	26.61	5.69	20	4.4%	0.21 [−0.41, 0.83]
Total (95% CI)			**408**			**408**	**100.0%**	**−1.85 [−2.51, −1.18]**

Heterogeneity: $Tau^2 = 2.55$; $Chi^2 = 345.71$, $df = 23$ ($P < 0.00001$); $I^2 = 93\%$
Test for overall effect: $Z = 5.42$ ($P < 0.00001$)

6.2. Experimental group: Signum PEEK Bond* and Control group: Visio.link.*

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI
Keul, 2014 (G1Da)	14.7	4.6	16	16.5	8	16	55.4%	−1.80 [−6.32, 2.72]
Keul, 2014 (G1Db)	11.2	10.9	16	12.8	12.1	16	17.8%	−1.60 [−9.58, 6.38]
Stawarczyk, 2013 (G1Ea)	54.3	23.1	16	53.3	26.7	16	3.8%	1.00 [−16.30, 18.30]
Stawarczyk, 2013 (G1Eb)	41.3	14.5	16	47	17.7	16	9.0%	−5.70 [−16.91, 5.51]
Stawarczyk, 2013 (G1Ec)	47.1	12.9	16	42.2	13.1	16	14.0%	4.90 [−4.11, 13.91]
Total (95% CI)			**80**			**80**	**100.0%**	**−1.07 [−4.44, 2.29]**

Heterogeneity: $Chi^2 = 2.51$, $df = 4$ ($P = 0.64$); $I^2 = 0\%$
Test for overall effect: $Z = 0.63$ ($P = 0.53$)

6.3. Experimental group: Monobond Plus/Heliobond* and Control group: Visio.link.*

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Keul, 2014 (G1Ba)	18.4	4.5	16	16.5	8	16	25.1%	1.90 [−2.60, 6.40]
Keul, 2014 (G1Bb)	20.7	7.6	16	12.8	12.1	16	24.5%	7.90 [0.90, 14.90]
Stawarczyk, 2018 (G1Ca)	1.57	4.28	20	28.58	6.27	20	25.4%	−27.01 [−30.34, −23.68]
Stawarczyk, 2018 (G2Ca)	5.9	10.5	20	26.61	5.69	20	25.0%	−20.71 [−25.94, −15.48]
Total (95% CI)			**72**			**72**	**100.0%**	**−9.61 [−26.38, 7.16]**

Heterogeneity: $Tau^2 = 285.78$; $Chi^2 = 149.96$, $df = 3$ ($P < 0.00001$); $I^2 = 98\%$
Test for overall effect: $Z = 1.12$ ($P = 0.26$)

*** - All groups were treated with Air Abrasion with 50 μm alumina powder;**

Figure 6. Meta-analysis of bonding agent effects on TBS, in MPa. Various adhesive systems (all used with 50-μm alumina powder air abrasion and Visio.link®) are compared together versus no-pretreatment Visio.link® controls in the upper section. Signum PEEK Bond® and Monobond Plus/Heliobond systems specifically are compared to no-pretreatment Visio.link® controls in the middle and bottom sections, respectively.

7.1. JUVORA - Experimental group: Plasma treatment* and Control group: No plasma treatment*

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Bötel, 2018 (G2Ab)	21.65	5.31	10	18.25	5.15	5	9.4%	3.40 [−2.19, 8.99]
Bötel, 2018 (G2Ac)	20.52	7.56	5	21.16	4.22	10	7.3%	−0.64 [−7.76, 6.48]
Bötel, 2018 (G3Ab)	28.69	4.2	5	18.25	5.15	5	9.0%	10.44 [4.62, 16.26]
Bötel, 2018 (G3Ac)	29.57	3.71	5	21.16	4.22	10	11.9%	8.41 [4.24, 12.58]
Bötel, 2018 (G4Ab)	25.66	2.81	5	18.25	5.15	5	10.1%	7.41 [2.27, 12.55]
Bötel, 2018 (G4Ac)	28.79	3.12	8	21.16	4.22	10	13.4%	7.63 [4.24, 11.02]
Bötel, 2018 (G5Ab)	24.48	3.12	5	18.21	5.15	5	9.9%	6.27 [0.99, 11.55]
Bötel, 2018 (G5Ac)	28.06	4.56	12	21.16	4.22	10	12.8%	6.90 [3.23, 10.57]
Schwitalla, 2017 (G3Aa)	19.8	2.46	10	18.29	1.84	10	16.1%	1.51 [−0.39, 3.41]
Total (95% CI)			**65**			**70**	**100.0%**	**5.74 [3.24, 8.24]**

Heterogeneity: $Tau^2 = 9.15$; $Chi^2 = 25.54$, df = 8 (P = 0.001); $I^2 = 69\%$
Test for overall effect: Z = 4.50 (P < 0.00001)

7.2. DC4420 - Experimental group: Plasma treatment* and Control group: No plasma treatment*

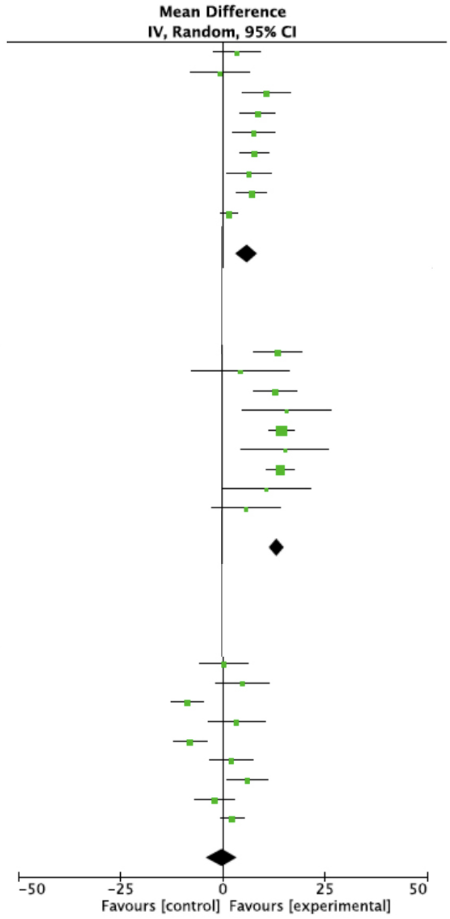
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Fixed, 95% CI
Bötel, 2018 (G2Ab)	30.95	6.35	5	17.31	1.93	5	10.0%	13.64 [7.82, 19.46]
Bötel, 2018 (G2Ac)	22.96	6.14	5	18.38	12.11	5	2.4%	4.58 [−7.32, 16.48]
Bötel, 2018 (G3Ab)	30.38	5.56	5	17.31	1.93	5	12.7%	13.07 [7.91, 18.23]
Bötel, 2018 (G3Ac)	34.2	1.87	5	18.38	12.11	5	2.9%	15.82 [5.08, 26.56]
Bötel, 2018 (G4Ab)	31.88	3.08	5	17.31	1.93	5	33.4%	14.57 [11.38, 17.76]
Bötel, 2018 (G4Ac)	33.83	1.47	5	18.38	12.11	5	3.0%	15.45 [4.76, 26.14]
Bötel, 2018 (G5Ab)	31.54	3.49	5	17.31	1.93	5	27.8%	14.23 [10.73, 17.73]
Bötel, 2018 (G5Ac)	29.31	2.6	5	18.38	12.11	5	2.9%	10.93 [0.07, 21.79]
Schwitalla, 2017 (G3Aa)	15.86	4.39	5	9.96	8.46	5	4.9%	5.90 [−2.45, 14.25]
Total (95% CI)			**45**			**45**	**100.0%**	**13.49 [11.65, 15.33]**

Heterogeneity: $Chi^2 = 6.49$, df = 8 (P = 0.59); $I^2 = 0\%$
Test for overall effect: Z = 14.35 (P < 0.00001)

7.3. DC4450 - Experimental group: Plasma treatment* and Control group: No plasma treatment*

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
Bötel, 2018 (G2Ab)	19.26	5.87	5	19.08	3.37	5	10.4%	0.18 [−5.75, 6.11]
Bötel, 2018 (G2Ac)	34.92	6.55	5	30.14	3.94	6	9.8%	4.78 [−1.77, 11.33]
Bötel, 2018 (G3Ab)	10.4	2.88	5	19.08	3.37	5	12.2%	−8.68 [−12.57, −4.79]
Bötel, 2018 (G3Ac)	33.44	7.15	5	30.14	3.94	6	9.4%	3.30 [−3.72, 10.32]
Bötel, 2018 (G4Ab)	10.99	3.24	5	19.08	3.37	5	12.0%	−8.09 [−12.19, −3.99]
Bötel, 2018 (G4Ac)	32.19	4.82	5	30.14	3.94	6	11.0%	2.05 [−3.22, 7.32]
Bötel, 2018 (G5Ab)	25.04	4.77	5	19.08	3.37	5	11.1%	5.96 [0.84, 11.08]
Bötel, 2018 (G5Ac)	28.19	4.28	5	30.14	3.94	6	11.3%	−1.95 [−6.85, 2.95]
Schwitalla, 2017 (G3Aa)	9.06	3.1	10	6.72	3.66	10	12.9%	2.34 [−0.63, 5.31]
Total (95% CI)			**50**			**54**	**100.0%**	**−0.26 [−4.01, 3.49]**

Heterogeneity: $Tau^2 = 26.11$; $Chi^2 = 44.46$, df = 8 (P < 0.00001); $I^2 = 82\%$
Test for overall effect: Z = 0.14 (P = 0.89)



* - All groups were treated with Air abrasion with 100 μm alumina powder + Visio.link;

Figure 7. Meta-analysis of plasma treatment effects on SBS, in MPa. Plasma pretreated specimens applied alone (control) or with air abrasion (100 μm alumina powder) with different brands of reinforced PEEK (Vestakeep DC4420® and DC4450® from Evonik Industries, Essen, GE; PEEK Juvora Dental Disk® from Juvora, Lancashire, UK).

Table 1. Characteristics of the specimens analyzed in each selected study.

Study	Specimens (Brand/Dimensions)	N total (N/ each group)	Veneering Composite	GROUPS				MAIN CONCLUSIONS
				Negative Control (Pretreatment)	Pretreatments	Positive Control (Adhesives)	Experimental Adhesive System	
Ates et al., 2018	PEEK BreCAM.BioHPP, 10X15X2.5mm	540 (90)	Crea.lign opaker A2, Crea.lign and Crea.lign paste A2 (Bredent)	No pretreatment	**G1**: Air Abrasion (50 µm alumina poder; 15s, 2.7atm); **G2**: Air Abrasion (silica-coated - Cojet system;15s, 2.7atm); **G3**: Laser (Er:YAG laser, 2.940nm, 150mJ, 10Hz, 1.5W); **G4**: Laser (Er:YAG laser, 2.940nm, 150mJ, 10Hz, 1.5W) + Air Abrasion (50 µm alumina powder 15s, 2.7atm); **G5**: Laser (Er:YAG laser, 2.940nm, 150mJ, 10Hz, 1.5W) + Air Abrasion (silica-coated - Cojet system;15s, 2.7 atm)	**Group A**: Visio.link, Bredent;	None	Air abrasion with Aluminum oxide and silica coating, combined or not to Er:YAG laser, improve bonding of veneering materials to PEEK frameworks
Bötel et al. 2018	PEEK Juvora Dental; DC 4420, Evonik; DC4450, Evonik; 10X15X2.5mm	272	VITA VM LC (Vita Zahnfabrik); GC Gradia (GC Europe); **c)** GC Gradia Direct Flo (GC Europe)	No pretreatment	**G1:** Air abrasion (100 µm alumina powder (Control); **G2**: Air abrasion (100 µm alumina powder + Plasma (Oxygen for 3 min); **G3**: Air abrasion (100 µm alumina powder + Plasma (Oxygen for 35 min); **G4**: Air abrasion (100 µm alumina powder) + Plasma (Argon/Oxygen for 3 min); **G5**: Air abrasion (100 µm alumina	**Group A**: Visio.link, Bredent;	None	The surface pretreatment of diverse PEEK types with low-pressure plasma, prior to veneering with composite, has a positive impact on the adhesive bonding between PEEK and composites. In addition, the light-bodied composite Gradia Direct Flo achieved the highest SBS.

					powder) + Plasma (Argon/Oxygen for 35 min);			
Çulhaoglu et al. 2017	PEEK BreCAM.BioHPP, 10mm diameterX4mm	198 (11)	Combo.lign (Bredent)	No pretreatment	**G1**: Air Abrasion (silica-coated - Cojet system - 3 bars); **G2**: Acetone Treatment 99% (60s); **G3**: Sulfuric Acid 98% (60s); **G4**: Air Abrasion (100 µm alumina powder - 2bars); **G5:** Laser (Yb:PL laser, 5W, 250ms)	**Group A**: Visio.link, Bredent;	None	Highest mean shear bond strengths were observed for acid-etched PEEK surfaces followed by laser-irradiated, airborne particle abraded, and silica coated surfaces.
Fokas et al., 2019	PEKK PEKKTON, 8mm diameter X3mm	250 (5)	Nexco, Ivoclar Vivadent	No pretreatment	**G1:** Air abrasion with 110 µm alumina powder - Rocatec Pre (2 bars); **G2:** Sulfuric Acid 98% (60s); **G3:** Air abrasion with 110 µm silica-coated alumina - Rocatec Plus (2bars); **G4:** Sulfuric Acid 98% (60s) + Air abrasion with 110 µm silica-coated alumina	**Grupo A:** Visio.link, Bredent;	**Grupo B:** Monobond-S, Ivoclar Vivadent	Air-abrasion with Rocatec Plus on polished or sulfuric-etched PEKK surface can significantly increase the tensile bonding stability as well as durability of resin composite to PEKK.
Keul et al. 2014	PEEK Dentokeep, 7mmX7mmX2mm	640(16)	Signum Composite Dentin A3 (Heraus Kulzer); Signum Ceramics Dentin A3 (Heraus Kulzer)	No pretreatment	**G1**: Air Abrasion (50 µm alumina powder); **G2**: Piranha Solution (30s); **G3**: Air Abrasion (50 µm alumina poder) + Piranha Solution (30s);	**Group A**: Visio.link, Bredent;	**Group B**: Monobond Plus/Heliobond (Ivoclar Vivadent); **Group C**: Clearfil Ceramic Primer (Kuraray Noritake Dental); **Group D**: Signum PEEK Bond I + II (Heraeus Kulzer)	Air abrasion, combined or not to piranha solution, followed by adhesive agents (Visio.link, Signum PEEK Bond, or Monobond Plus/Heliobond) seemed to generate reliable bond strengths for the veneering of PEEK with resin composites.

Lee et al. 2014	PEKK Pekkton Ivory, 7mmX7mmX2mm	150 (10)	Filtek Z350 XT (3M ESPE)	N/D	**G1**: Sulfuric Acid 95% (60s); **G2**: Air Abrasion (50 µm alumina powder; 0.5MPa, 20s); **G3**: Air Abrasion (110 µm silica-coated; 0.5MPa, 20s);	**Group A**: Visio.link, Bredent;	**Group B**: Luxatemp Glaze & Bond (DMG); **Group C**: Single Bond Universal (3M ESPE); **Group D**: All-Bond Universal (Bisco), **Group E:** Monobond Plus + Heliobond (Ivoclar Vivadent)	The combination of air-abrasion with MDP or MMA-containing bond materials are recommended. Single Bond Universal can be an effective bonding material to PEKK.
Schwitalla et al. 2017	PEEK Juvora Dental; DC 4420, Evonik; DC4450, Evonik; 10x15x2.5mm	120 (10)	VITA VM LC (Vita Zahnfabrik)	No pretreatment	**G1**: Plasma (Argon + Oxygen, 35min, 0.3mbar, 100kHz, 200w); **G2**: Air Abrasion (100 µm alumina powder; **G3**: Air Abrasion (100 µm alumina + Plasma (Argon + Oxygen, 35min, 0.3mbar, 100kHz, 200w);	**Group A**: Visio.link, Bredent;	None	Air abrasion and surface activation with low-pressure argon/oxygen plasma, in combination with an adhesive agent, increases shear bond strength, especially in unfilled PEEK material.
Stawarczyk et al. 2013	PEEK Dentokeep, 7mmX7mmX2mm	576 (16)	Sinfony (3M ESPE); GC Gradia (GC Europe); VITA VM LC (VITA Zahnfabrik)	No pretreatment	**G1:** Air Abrasion (50µm alumina powder)	**Group A**: Visio.link, Bredent;	**Grupo B**: Z-Prime Plus (BISCO), **Group C**: Ambarino P60 (Creamed), **Group D**: Monobond Plus (Ivoclar Vivadent); **Group E**: Signum PEEK Bond I+II (Heraeus Kulzer)	Pre-treatment with Monobond Plus increased the TBS values. The highest TBS before and after thermocycling between PEEK and all tested veneering resins was observed for groups pre-treated with Visio.link and Signum PEEK Bond.
Stawarczyk et al. 2014	PEEK Dentokeep, 7mmX7mmX2mm	720 (20)	Sinfony (3M ESPE); VITA VM LC (VITA Zahnfabrik)	No pretreatment	**G1:** Sulfuric Acid (98%); **G2:** Piranha Solution;	**Group A**: Visio.link, Bredent;	**Grupo B:** Signum PEEK Bond I+II (Heraeus Kulzer)	Adhesive systems should be applied to ensure a durable bond. Acid pretreatment of PEEK surface is not required.

								The veneering resin composites show no effect on the results.
Stawarczyk et al. 2017	PEKK Pekkton Ivory, 10mmX10mmX4mm	1200 (20)	Anaxblend Opaquer Paste (Anaxdent); Anaxblend Dentin Flow (Anaxdent); Anaxblend Dentin Paste (Anaxdent)	No pretreatment	**G1**: Air abrasion (100 µm alumina powder); **G2**: Air Abrasion (100 µm alumina powder) + Plasma (Oxygen, 15s, 20W);	**Group A**: Visio.link, Bredent;	**Group B:** PEKK Bond (Anaxdent)	Oxygen plasma treatment, in combination with adhesives increases TBS. Visio.link showed higher TBS to PEKK than did PEKK Bond. Flowable veneering composite also increased TBS in comparison to packable veneering composite.
Stawarczyk et al. 2018	PEEK - Tizian PEEK, 10X10X3mm	400 (20)	Dialog Occlusal (Schütz Dental)	N/D	**G1**: Air Abrasion (50 µm alumina powder; 0.05MPa); **G2**: Air Abrasion (50 µm alumina powder; 0.35MPa); **G3**: Air Abrasion (100 µm alumina poder; 0.05MPa); **G4**: Air Abrasion (100 µm alumina poder; 0.35MPa); **G5**: Air Abrasion (100 µm silica-coated – Rocatec; 0.35MPa);	**Group A**: Visio.link, Bredent;	**Group B**: Scotchbond Universal (3M ESPE); **Group C**: Monobond Plus + Heliobond (Ivoclar Vivadent); **Group D:** Dialog Bonding Fluid (Schütz Dental).	PEEK conditioning with Visio.link increased TBS values with the smallest number of prefailured specimens compared to the remaining adhesive systems. The grain size of the air-abrasion powder particle did not show an effect on the TBS.

Supplemental Table 1 - Electronic database and search strategy (15/03/2019).	
Pubmed	(((("polyetheretherketone" OR "polyetheretherketones" OR "PEEK" OR "polyetherketoneketone" OR "polyetherketoneketones" OR "PEKK") AND ("Dentistry"[MeSH:NoExp] OR "Dentistry" [Title/Abstract] OR "dental" OR "oral"))) AND ("surface treatment" OR "surface treatments" OR "roughness" OR "surface roughness" OR "surface properties"[MeSH Terms] OR "surface properties" OR "surface property" OR "adhesiveness"[MeSH Terms] OR "adhesiveness" OR "adhesives"[MeSH Terms OR "adhesives" OR "adhesive" OR "dental bonding"[MeSH Terms] OR "dental bonding" OR "adhesive bonding" OR "Dentin-Bonding Agents"[MeSH:noexp] OR "Dentin-Bonding Agent" OR "Dentin-Bonding Agents" OR "Dental Debonding"[MeSH Terms])) AND ("bond strength" OR "bond strengths" OR "Dental Stress Analysis"[MeSH Terms] OR "Dental Stress Analysis" OR "Dental Stress" OR "Fractures, Stress"[MeSH Terms] OR "stress fracture" OR "stress fractures" OR "shear strength"[MeSH Terms] OR "shear strength" OR "shear strengths" OR "shear bond strength" OR "shear bond strengths" OR "tensile strength"[MeSH Terms] OR "tensile strength" OR "tensile strengths" OR "tensile bond strength" OR "tensile bond strengths" OR "Prosthesis Failure"[MeSH:noexp] OR "Prosthesis Failure" OR "Prosthesis Failures")
Web of Science	(((TÓPICO: ((((("polyetheretherketone" OR "polyetheretherketone") OR "PEEK") OR "polyetherketonketon") OR "polyetherketoneketone") OR "PEKK") AND TÓPICO: (("Dentistry" OR "dental") OR "oral")) AND TÓPICO: ((((((((((("surface treatment" OR "surface treatments") OR "roughness") OR "surface roughness") OR "surface properties") OR "surface property") OR "adhesiveness") OR "adhesives") OR "adhesive") OR "dental bonding") OR "adhesive bonding") OR "Dentin-Bonding Agent") OR "Dentin-Bonding Agents") OR "Dental Debonding")) AND TÓPICO: ((((((((((((("bond strength" OR "bond strengths") OR "Dental Stress Analysis") OR "Dental Stress") OR "stress fracture") OR "stress fractures") OR "shear strength") OR "shear strengths") OR "shear bond strength") OR "shear bond strengths" "tensile strength") OR "tensile strengths") OR "tensile bond strength") OR "tensile bond strengths") OR "Prosthesis Failure") OR "Prosthesis Failures"))
Scopus	TITLE-ABS-KEY ("polyetheretherketone" OR "polyetheretherketones" OR "PEEK" OR "polyetherketoneketone" OR "polyetherketoneketones" OR "PEKK") AND TITLE-ABS-KEY ("Dentistry" OR "dental" OR "oral") AND TITLE-ABS-KEY ("surface treatment" OR "surface treatments" OR "roughness" OR "surface roughness" OR "surface properties" OR "surface property" OR "adhesiveness" OR "adhesives" OR "adhesive" OR "dental bonding" OR "adhesive bonding" OR "Dentin-Bonding Agent" OR "Dentin-Bonding Agents" OR "Dental Debonding") AND TITLE-ABS-KEY ("bond strength" OR "bond strengths" OR "Dental Stress Analysis" OR "Dental Stress" OR "stress fracture" OR "stress fractures" OR "shear strength" OR "shear strengths" OR "shear bond strength" OR "shear bond strengths" "tensile strength" OR "tensile strengths" OR "tensile bond strength" OR "tensile bond strengths" OR "Prosthesis Failure" OR "Prosthesis Failures")
Embase	('polyetheretherketone':ti,ab,kw OR 'polyetheretherketones':ti,ab,kw OR 'peek':ti,ab,kw OR 'polyetherketoneketone':ti,ab,kw OR 'polyetherketoneketones':ti,ab,kw OR 'pekk':ti,ab,kw) AND ('Dentistry':ti,ab,kw OR 'dental':ti,ab,kw OR 'oral':ti,ab,kw)AND ('surface treatment':ti,ab,kw OR 'surface treatments':ti,ab,kw OR 'roughness':ti,ab,kw OR 'surface roughness':ti,ab,kw OR 'surface properties':ti,ab,kw OR 'surface property':ti,ab,kw OR 'adhesiveness':ti,ab,kw OR 'adhesives':ti,ab,kw OR 'adhesive':ti,ab,kw OR 'dental bonding':ti,ab,kw OR 'adhesive bonding':ti,ab,kw OR 'dentin-bonding agent':ti,ab,kw OR 'dentin-bonding agents':ti,ab,kw OR 'dental debonding':ti,ab,kw) AND ('bond strength':ti,ab,kw OR 'bond strengths':ti,ab,kw OR 'dental stress analysis':ti,ab,kw OR 'dental stress':ti,ab,kw OR 'stress fracture':ti,ab,kw OR 'stress fractures':ti,ab,kw OR 'shear strength':ti,ab,kw OR 'shear strengths':ti,ab,kw OR 'shear bond strength':ti,ab,kw OR 'shear bond strengths':ti,ab,kw OR 'tensile strength':ti,ab,kw OR 'tensile strengths':ti,ab,kw OR 'tensile bond strength':ti,ab,kw OR 'tensile bond strengths':ti,ab,kw OR 'prosthesis failure':ti,ab,kw OR 'prosthesis failures':ti,ab,kw)

LILACS and BBO	(tw:("polyetheretherketone" OR "polyetheretherketones" OR "PEEK" OR "polyetherketoneketone" OR "polyetheketoneketones" OR "PEKK" OR "polieteretercetona" OR "polieteretercetonas" OR "polietercetonacetona" OR "polietercetonacetonas")) AND (tw:("Dentistry" OR "Odontologia" OR "dental" OR "oral" OR "dentária")) AND (tw:("surface treatment" OR "surface treatments" OR "roughness" OR "surface roughness" OR "surface properties" OR "surface property" OR "adhesiveness" OR "adhesives" OR "adhesive" OR "dental bonding" OR "adhesive bonding" OR "adhesive bonding system" OR "adhesive bonding systems" OR "Dentin-Bonding Agent" OR "Dentin-Bonding Agents" OR "Dental Debonding" OR "tratamento de superfície" OR "tratamentos de superfície" OR "rugosidade" OR "rugosidade superficial" OR "propriedade de superfície" OR "propriedades de superfície" OR "adesão" OR "adesividade" OR "adesivos" OR "adesivo" OR "colagem dentária" OR "adesão dentária" OR "adesões dentárias" OR "agente adesivo" OR "sistema adesivo" OR "sistemas adesivos" OR "adesivos dentinários" OR "adesivo dentinário" OR "agente de adesão dentária" OR "agentes de adesão dentária" OR "agente de união dentinária" OR "agentes de união dentinária" OR "união dentária" OR "descolagem dentária" OR "tratamiento superficial" OR "tratamientos superficiales" OR "rugosidad" OR "rugosidad superficial" OR "propiedade de superficie" OR "propiedad superficial" OR "adhesividad" OR "adhesivos" OR "adhesivo" OR "recubrimiento dental adhesivo" OR "unión dental" OR "unión adhesiva" OR "sistema de unión adhesiva" OR "sistemas de unión adhesiva" OR "recubrimientos dentinarios" OR "agente de unión de dentina" OR "agentes de unión de dentina" OR "agente de unión de dentina" OR "agentes de unión de dentina" OR "desconsolidación dental" OR "eliminación de adelgazamiento dental")) AND (tw:("bond strength" OR "bond strengths" OR "Dental Stress Analysis" OR "dental stress" OR "stress fracture" OR "stress fractures" OR "shear strength" OR "shear strengths" OR "shear bond strength" OR "shear bond strengths" OR "tensile strength" OR "tensile strengths" OR "tensile bond strength" OR "tensile bond strengths" OR "Prosthesis Failure" OR "Prosthesis Failures" OR "força de adesão" OR "força de adesão" OR "análise do estresse dentário" OR "análises do estresse dentário" OR "estresse dentário" OR "fraturas de estresse" OR "fratura de estresse" OR "fraturas por estresse" OR "resistência ao cisalhamento" OR "resistência de união ao cisalhamento" OR "resistência à tração" OR "força de tração" OR " Falha protética" OR "Falha de Prótese" OR "Falhas de Prótese" OR "fuerza de adhesión" OR "fuerza de adhesión" OR "análisis del estrés dental" OR "estrés dental" OR "fracturas por estrés" OR "fractura por estrés" OR "fracturas por estrés" OR "resistência al corte" OR "resistencia al cizallamiento" OR "resistencia de unión al cizallamiento" OR "resistencia a la tracción" OR "fuerza de tracción" OR "Falla protética "or" Falla de prótesis" OR "Fallas de prótesis")) AND (instance:"regional")
Google Scholar	"polyetheretherketone" OR "polyetherketoneketone" AND "Dentistry"